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Discontinuities in GEOS-5.4.1 Dataset and Their Comparison to MERRA-2 and ERA-5

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Background

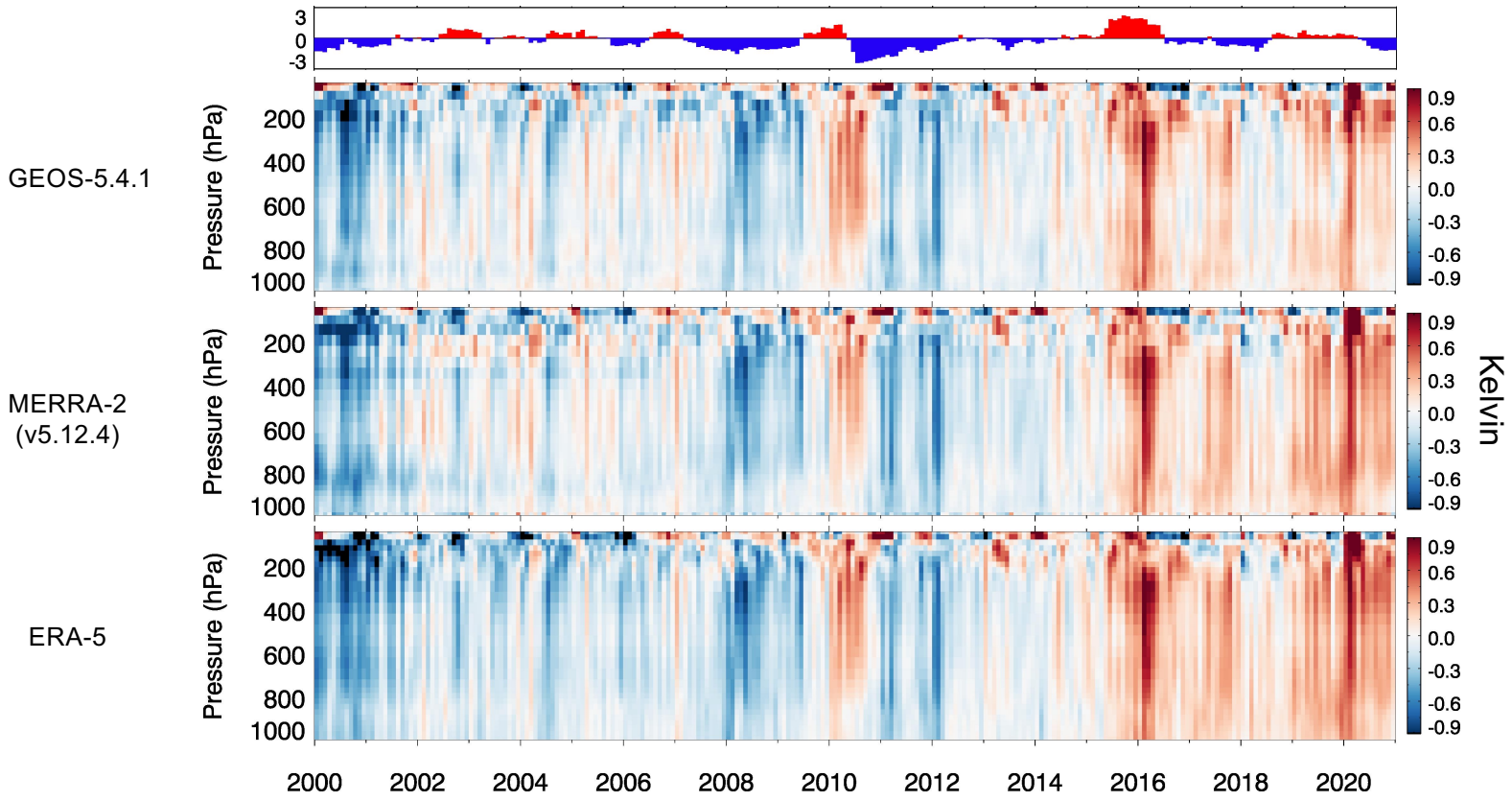
- GEOS-5.4.1 temperature and water vapor profiles are being used for CERES processing. The free version (v5.4.1) is used throughout the CERES record for continuous temperature and water vapor.
- The most recent version of GMAO FP is v5.27.1 (So v5.4.1 is kind of old).
- MERRA-2 uses v5.12.4, and MERRA used v5.2.0 (GEOS-5.4.1 is somewhere between MERRA and MERRA-2).
- Despite the version freeze, if there are changes in the observational systems (e.g., termination of satellite missions, sensor sensitivity changes), the GEOS-5.4.1 dataset can experience significant changes.

Objectives

- Examine if there exist abrupt changes in GEOS-5.4.1 datasets
- Compare the GEOS-5.4.1 changes with other reanalysis datasets (e.g., MERRA-2, ERA-5) to understand if similar changes are also shown in other datasets
- Discuss impacts of the GEOS-5.4.1 changes on the CERES processing

Area weighted; climatology is obtained using 2003-2020

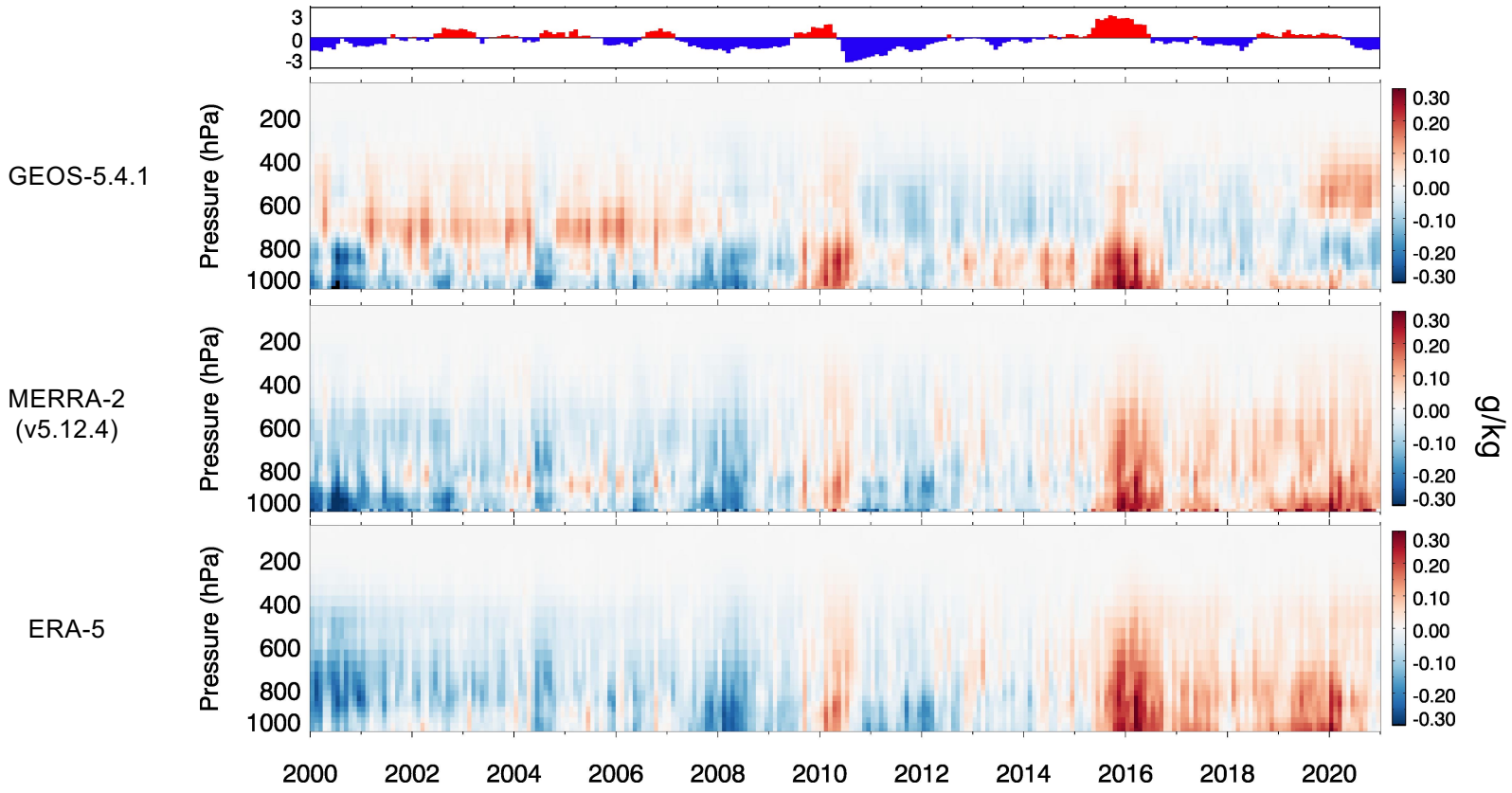
60S-60N Land+Ocean Temperature Anomaly (K)



Temperature anomalies are closely related to ENSO events, and the three datasets show similar features. After 2015/16 El Niño, the temperature warming in G541 is slightly weaker than MERRA-2 or ERA-5.

Area weighted; climatology is obtained using 2003-2020

60S-60N Land+Ocean Specific Humidity Anomaly (g/kg)

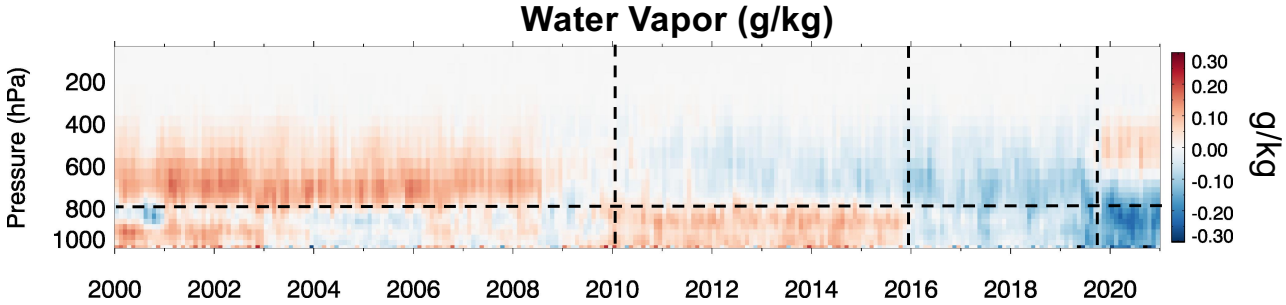


- MERRA-2 and ERA-5 WV anomalies are well correlated with temperature anomalies.
- GEOS-5.4.1 shows a discontinuity across the 800-hPa pressure level. Also abrupt changes around 2010, 2016, and 2019.

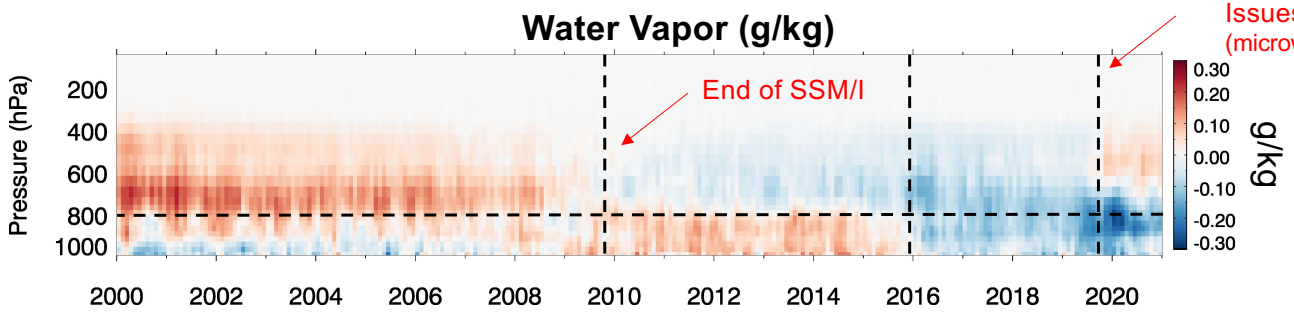
60S-60N Land+Ocean

Area weighted; climatology is obtained using 2003-2020

[G-5.4.1 WV Anomalies] – [MERRA-2 WV Anomalies]



[G-5.4.1 WV Anomalies] – [ERA-5 WV Anomalies]

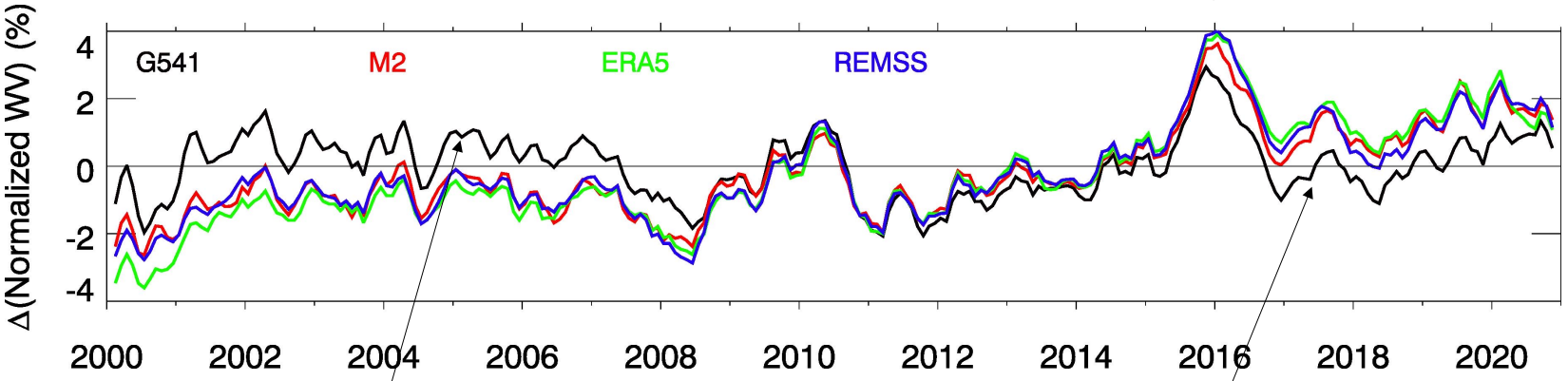


- The differences between G541 and ERA5 are similar to those between G541 and MERRA-2.
- This implies that the differences are mainly driven by G541 problems.
- The discontinuities in G541 might be related to input observing data changes.

Normalized Anomalies (%) of Total Column (TOA–SFC) WV (kg m^{-2}): MW Measurement Included

60S–60N Ocean due to the availability of REMSS

Area weighted; climatology is obtained using 2003-2020 3-month running means



- REMSS: Remote Sensing Systems (RSS) Version-7 microwave radiometer total columnar water vapor values) (Wentz 2015). TPW values come from the following SSM/I F08 through F15, SSMIS F16 and F17, AMSR-E, WindSat, and AMSR2.

- MERRA-2 and ERA-5 WV anomalies are close to RSS (MW obs) anomalies. (Note that RSS is used for MERRA-2 assimilation)
- GOES-5.4.1 WV anomalies are positively biased before 2008, and negatively biased after 2014.

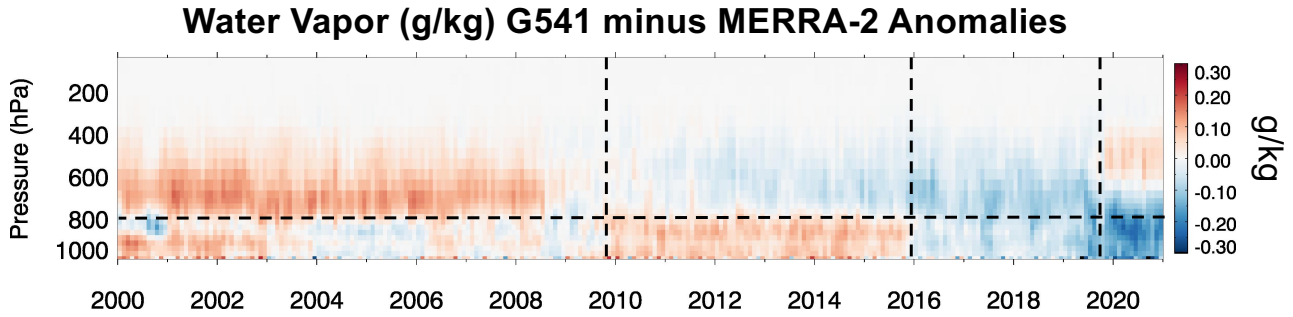
Decadal Trend of Normalized Anomalies (%) of Vertically Integrated WV (Using 3-month-running mean anomalies for the 2000–2020 period) Over the 60S–60N Domain

Normalized Anomalies (%) of Vertically Integrated WV (kg m^{-2})	Decadal Trend (%/10year) ± [95% Confidence Interval]		
	GEOS-5.4.1	MERRA-2	ERA-5
TOA-400hPa	+1.4 ± 0.55	+2.5 ± 0.48	+3.9 ± 0.46
400-600hPa	–0.2 ± 0.52	+2.5 ± 0.27	+3.6 ± 0.31
600-800hPa	–1.3 ± 0.23	+2.0 ± 0.19	+2.5 ± 0.22
800hPa–SFC	+0.8 ± 0.19	+1.4 ± 0.16	+1.5 ± 0.18
TOA–SFC	+0.1 ± 0.19	+1.7 ± 0.18	+2.0 ± 0.19

MERRA-2 and ERA-5 show larger increasing WV trends than GEOS-5.4.1.

WV Discontinuities in GEOS-5.4.1

- Signs of G541 anomalies flip across the 800-hPa pressure level.
- Prior to 2010, G541 WV anomalies above the 800-hPa pressure level are positively biased.
- From 2010 to 2015, G541 WV anomalies below the 800-hPa pressure level are positively biased.
- From 2016 to 2019, G541 WV anomalies for all altitudes are negatively biased.
- Beginning of 2020, 400-600 hPa G541 WV anomalies are largely positively biased.



Is it possible that the G541 WV discontinuities affect CERES clear-sky flux estimations?

EBAF TOA Clear-Sky LW Fluxes for Total Regions (Loeb et al. 2020)

$$F_{cs}^{o}(CldRem) = F_{cs}^{o} + \Delta^{c}$$

G541 T & q

Monthly clear-sky fluxes from all hourly grid boxes (Useful for model validations & CRE estimations)

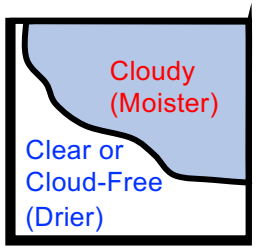
Monthly adjustment factor (Sampling correction)

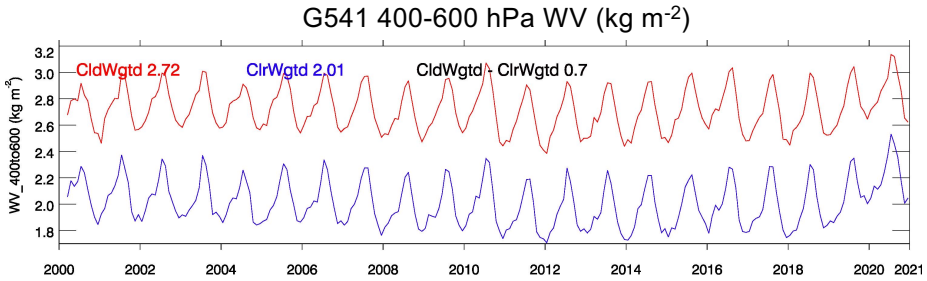
Monthly observed clear-sky fluxes from cloud-free hourly grid boxes

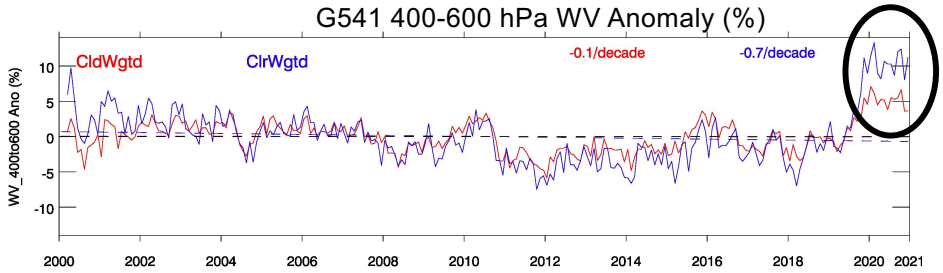
$$\Delta^{c} = F_{cs}^{c}(CldRem) - F_{cs}^{c}(ObsWgt)$$

Computed clear-sky fluxes by sampling all hourly grid boxes

Computed clear-sky fluxes by sampling cloud-free hourly grid boxes

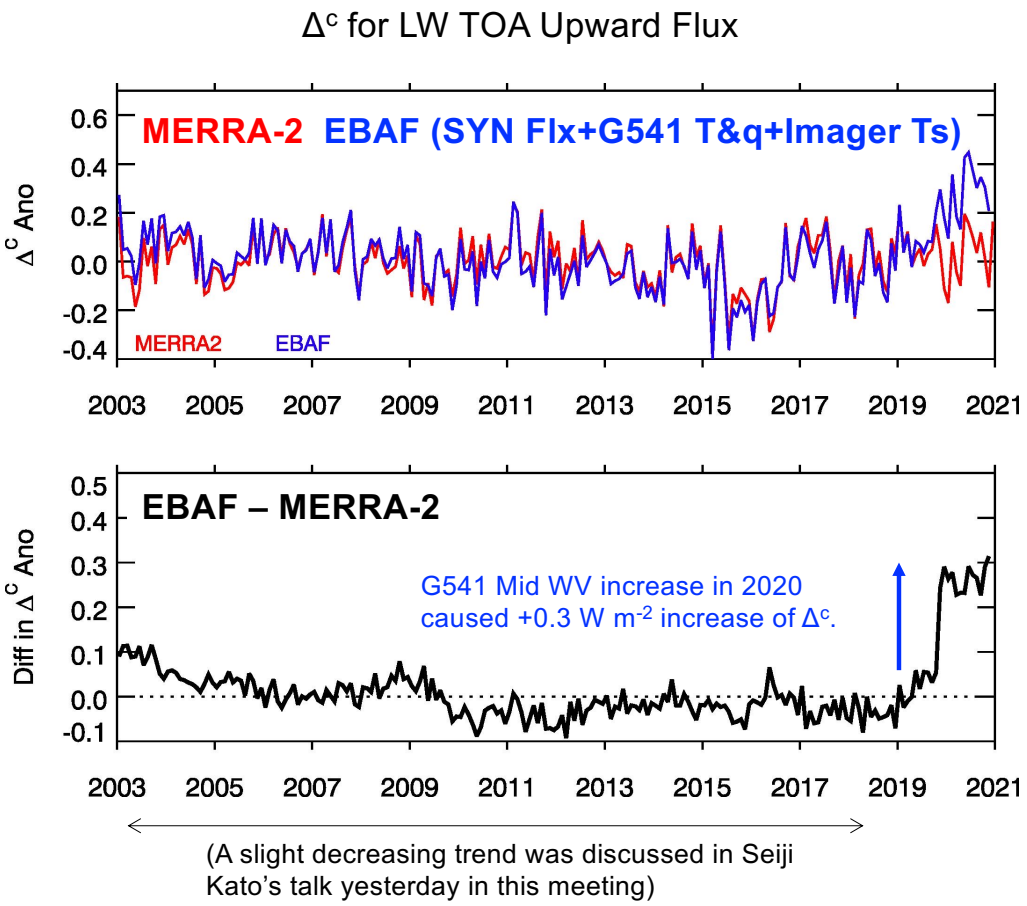






- Cloudy regions are usually moister than clear regions. Therefore, by including cloudy grid boxes in TOA clear-sky LW flux computations, the flux would be smaller ($\Delta^c < 0$), if there are no temperature inversions.
- In 2020, 400-600 hPa WV increased more significantly over clear regions than over cloudy regions. This means that the differences in humidity between clear and cloudy regions got smaller and the magnitude of Δ^c got smaller (smaller negative).

MERRA-2 vs G541 (EBAF) TOA LW Δ^c



(A slight decreasing trend was discussed in Seiji Kato's talk yesterday in this meeting)

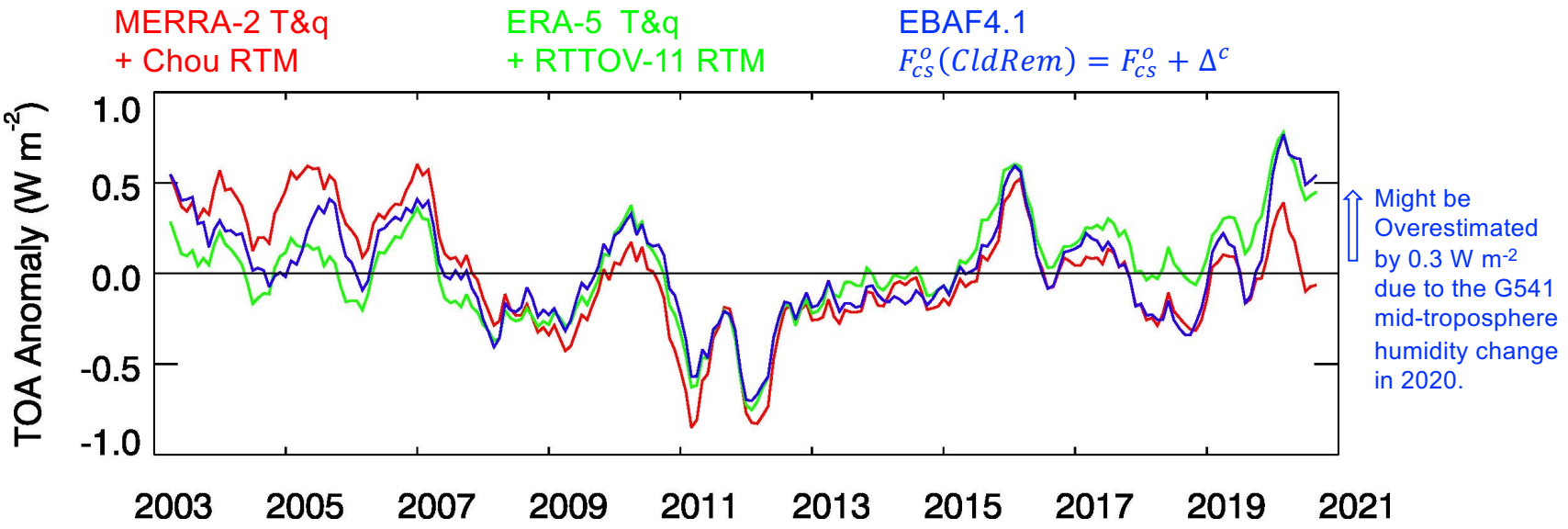
Smaller correction
(smaller negative Δ^c)
Smaller flux differences between clear and cloudy regions

Larger correction
(larger negative Δ^c)
Larger flux differences between clear and cloudy regions

- As mid-troposphere WV increased more over clear regions than over cloudy regions, the WV differences between clear and cloudy regions got smaller in 2020. As a result, smaller negative correction is needed for EBAF (G541) in 2020, than for MERRA-2.
- **The Δ^c differences in between EBAF and MERRA-2 is mostly < 0.1 W m^{-2}, but it increased up to 0.3 W m^{-2} in 2020.**

60ºS–60ºN Clear-Sky TOA Upward LW Flux Anomalies

6 running month means
Climatology from 2003/01 to 2019/12 for all datasets



- EBAF clear-sky TOA LW upward fluxes are slightly affected by Δ^c, +0.3 W m^{-2} due to the GEOS-5.4.1 WV changes in 2020.
- Good agreement is shown from 2009–2016, while the fluxes diverge after 2017.
- Further investigation is needed with ERA-5 Δ^c (not shown in this talk).

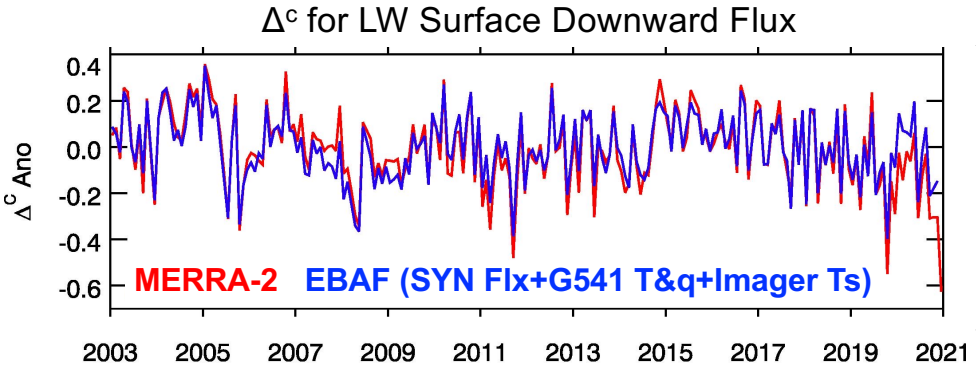
EBAF Clear-Sky Surface Downward LW Fluxes for Total Regions (Kato et al. 2018; Loeb et al. 2020)

$$F_{cs}^{o}(CldRem) = F_{cs}^{o} + \Delta^{c}$$

G541 T & q

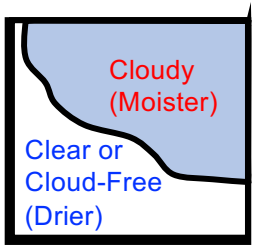
Computed fluxes for **cloud-free** grid boxes **constrained** by TOA flux observations ("Constraining" means RT model inputs are tuned to produce TOA fluxes close to observations)

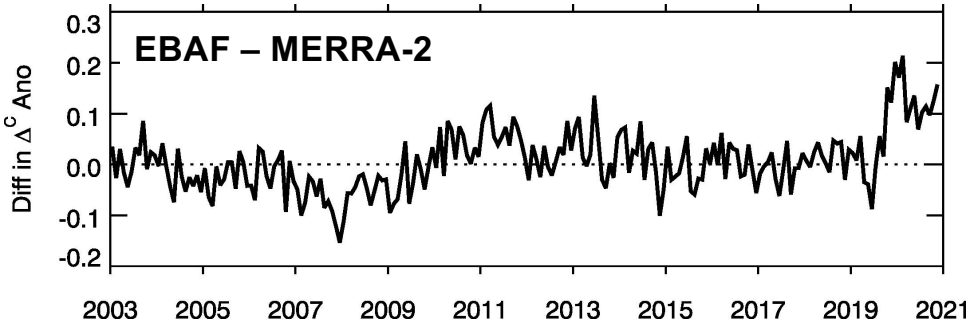
Monthly adjustment factor (Sampling correction)



Larger correction (larger positive Δ^c)
Larger flux differences between clear and cloudy regions

Smaller correction (smaller positive Δ^c)
Smaller flux differences between clear and cloudy regions

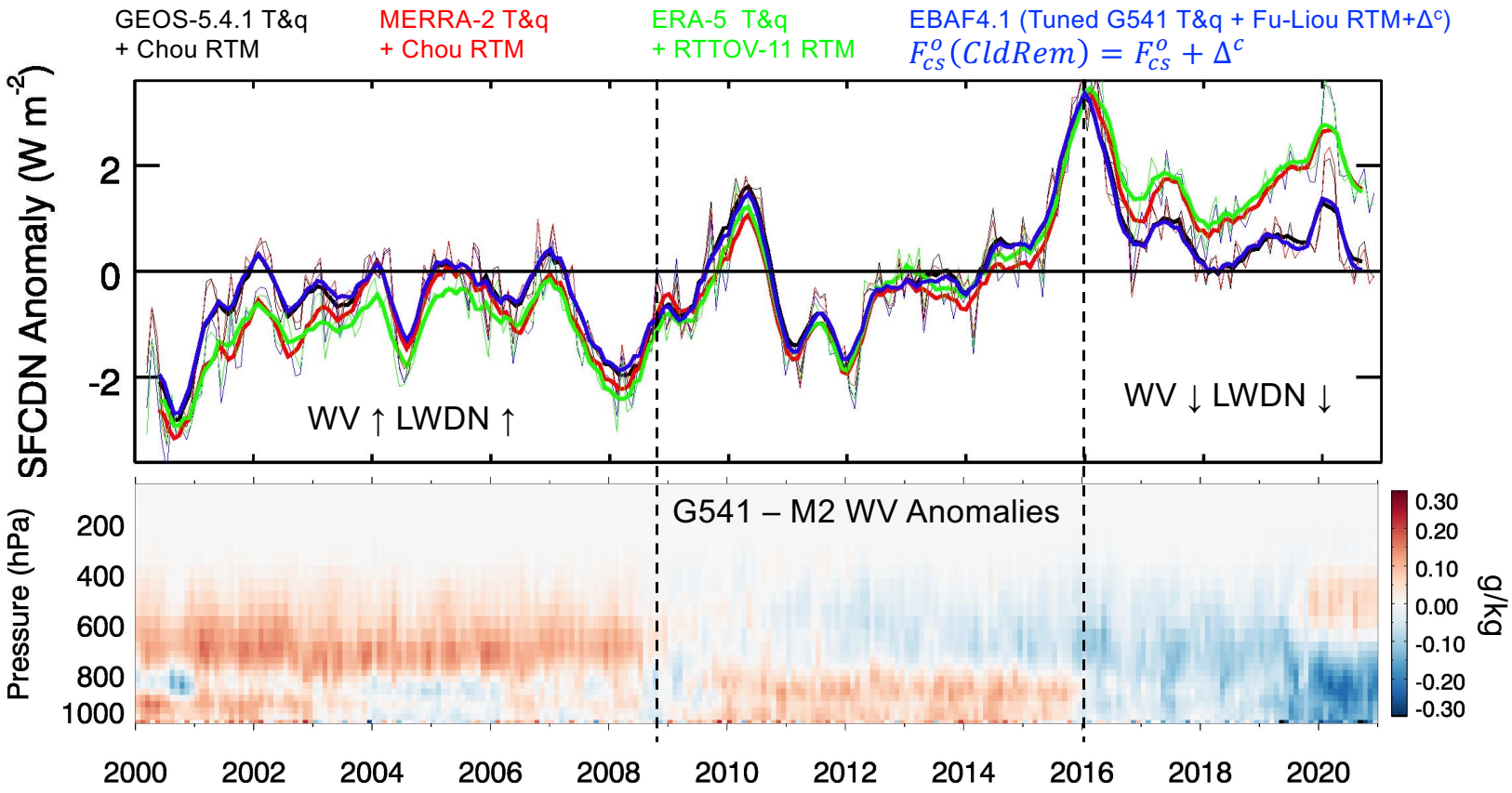




- According to MERRA-2, the boundary layer humidity (850 hPa-SFC) over clear regions increased more than over cloudy regions. As a result, the humidity differences between cloudy and clear regions got reduced and Δ^c became smaller posiive. G541 does not show this feature.
- The Δ^c differences between EBAF and MERRA-2 are mostly < 0.1 W m^{-2} and it slightly increased up to 0.2 W m^{-2} in 2020.

60ºS–60ºN Clear-Sky Surface Downward LW Flux Anomalies

6 running month means
Climatology from 2003-2019
for all datasets



In EBAF processing, G541 upper troposphere (200-500hPa) humidity is corrected using AIRS, but mid and low troposphere humidity can still affect surface LW fluxes.

Summary

- Water vapor amounts in GEOS-5.4.1 have discontinuities across 800 hPa pressure level, and abrupt changes happened in the beginning of 2010, 2016, and 2020.
- The abrupt WV changes in GEOS-5.4.1 slightly affect the CERES EBAF TOA clear-sky flux computations due to change of the adjustment factor (Δ^c) in 2020.

$$F_{cs}^{o}(CldRem) = F_{cs}^{o} + \Delta^{c}$$ ~ up to 0.3 W m^{-2}

- For CERES EBAF surface downward flux estimations, positive biases of G541 WV anomalies before 2010 caused positive biases of surface downward LW flux anomalies. After 2016, negative biases in G541 WV anomalies caused underestimation of surface downward LW flux anomalies.

$$F_{cs}^{o}(CldRem) = F_{cs}^{o} + \Delta^{c}$$ ~ up to 1 W m^{-2}

Thank you for your attention!